US005144825A

United States Patent [19]
Burg et al.

[11] Patent Number: 5,144,825
[45] Date of Patent: Sep. 8, 1992

[54] ELEVATED TEMPERATURE ENVELOPE FORMING

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[73] Assignee: The Boeing Company, Seattle, Wash.

[21] Appl. No.: 589,058

[22] Filed: Sep. 27, 1990

[51] Int. Cl.[5] B21D 26/02
[52] U.S. Cl. 72/60; 72/63; 29/889.7; 29/421.1
[58] Field of Search 29/889.7, 889.71, 889.72, 29/421.1; 72/60, 63

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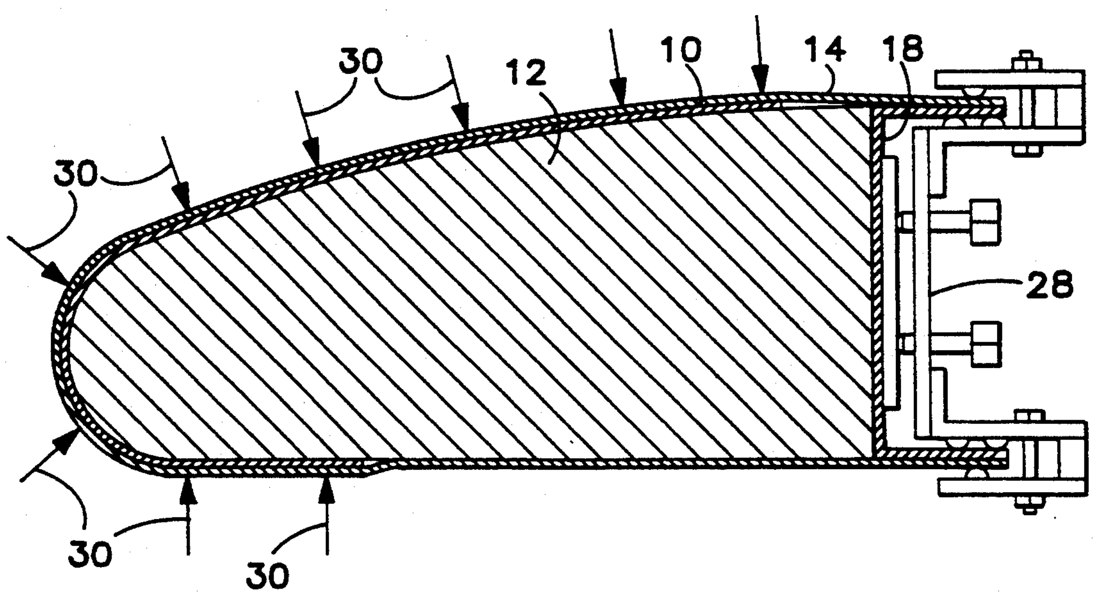
[57] ABSTRACT

Elevated temperature envelope forming includes enclosing a part blank and form tool within an envelope sealed against the atmosphere, heat treating the combination while forming pressure holds the envelope and part against the form tool, and allowing part cool down to occur in an inert atmosphere with forming pressure removed. The forming pressure is provided by evacuating the envelope and may be aided by differential force applied between the envelope and the form tool.

15 Claims, 8 Drawing Sheets



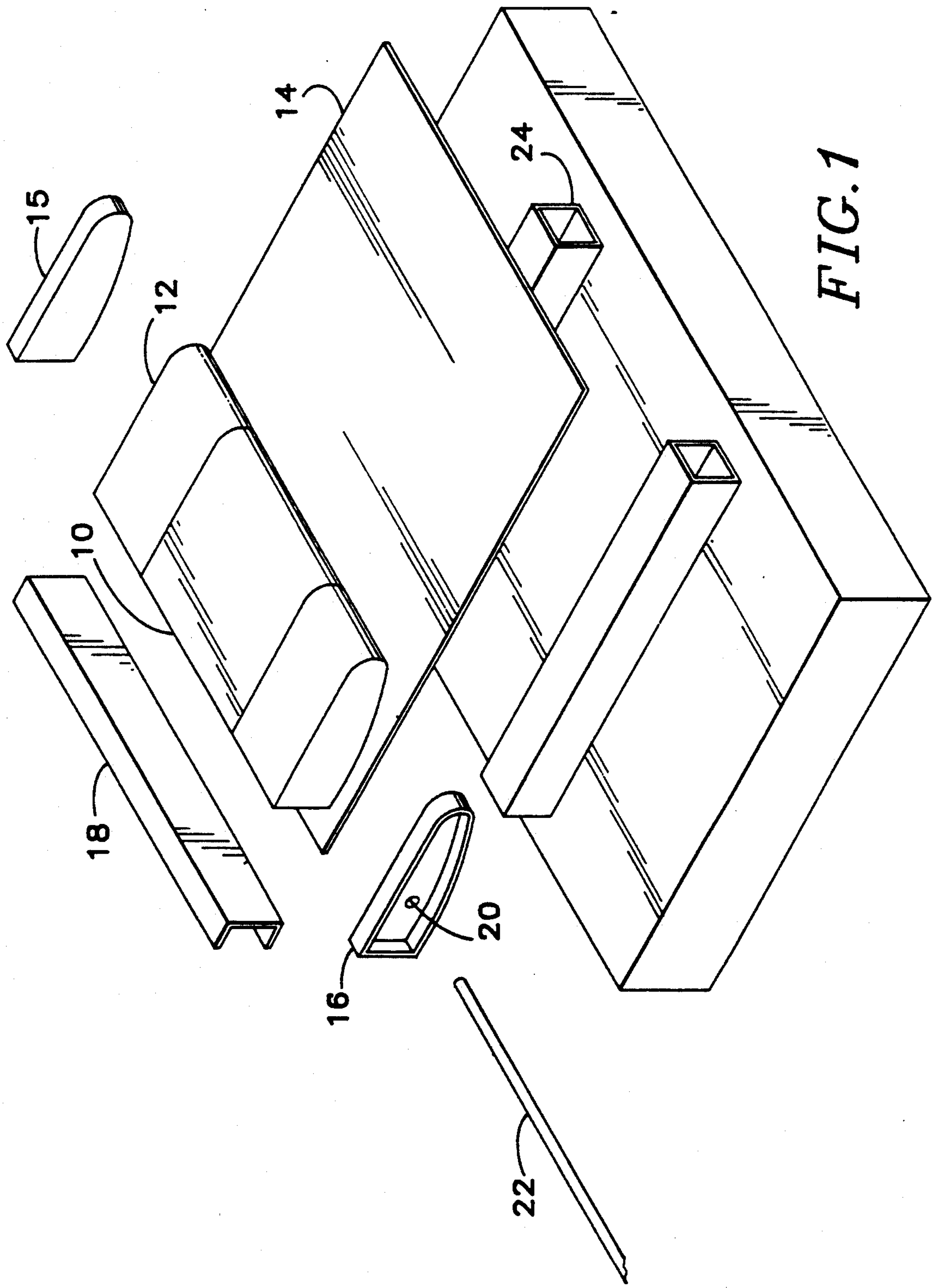


FIG. 1

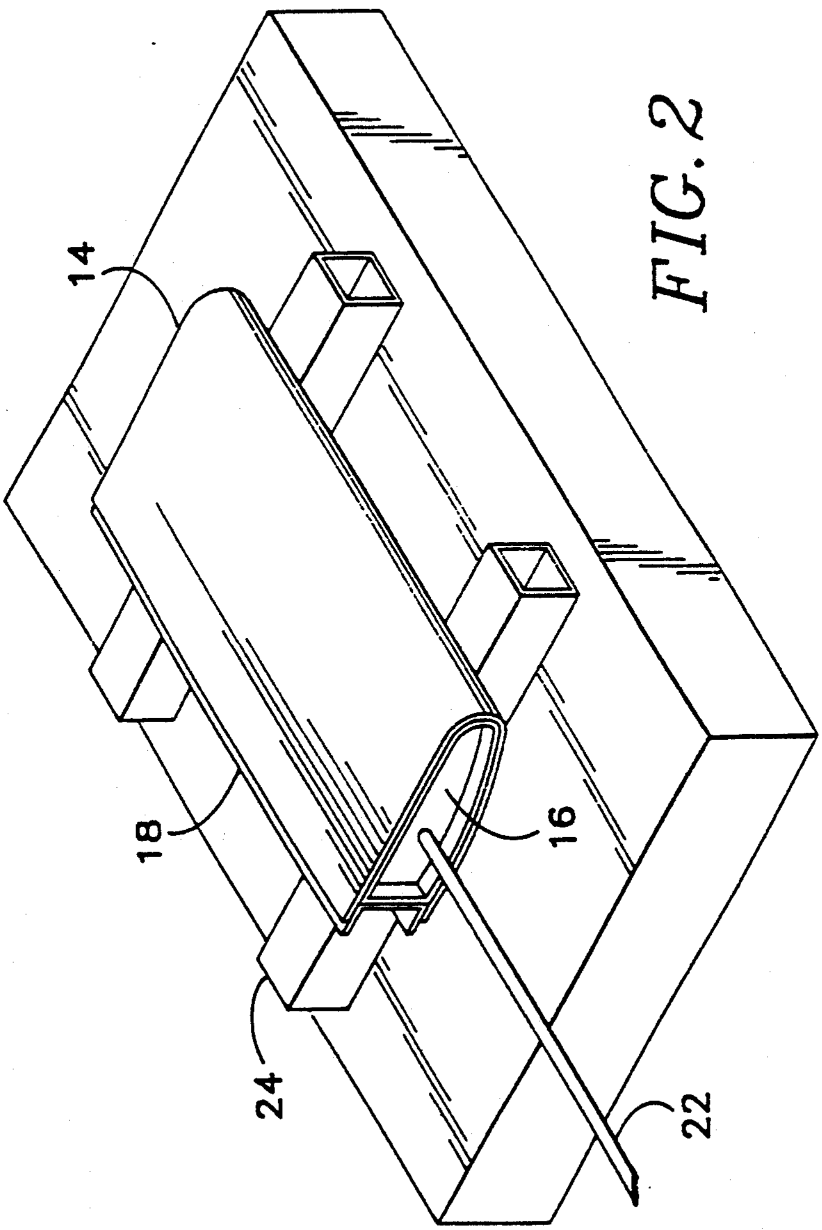


FIG. 2

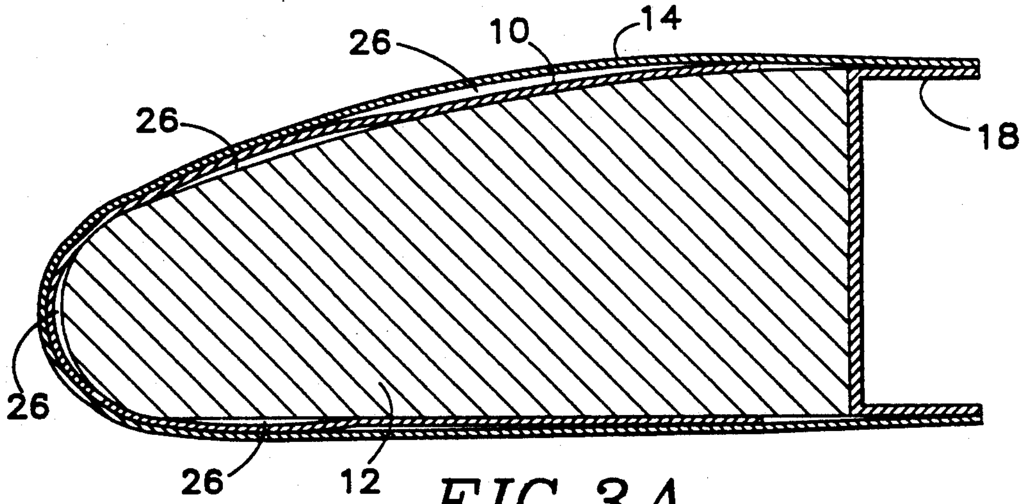


FIG. 3A

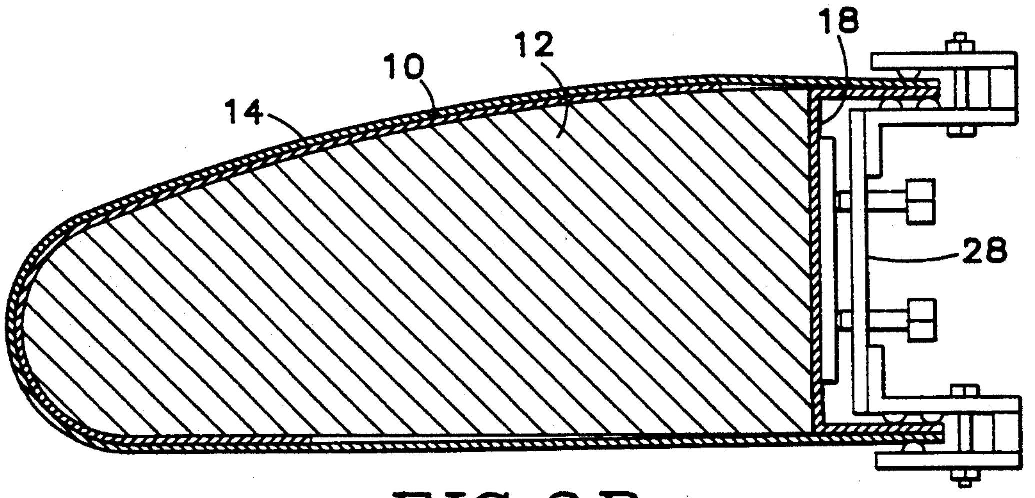


FIG. 3B

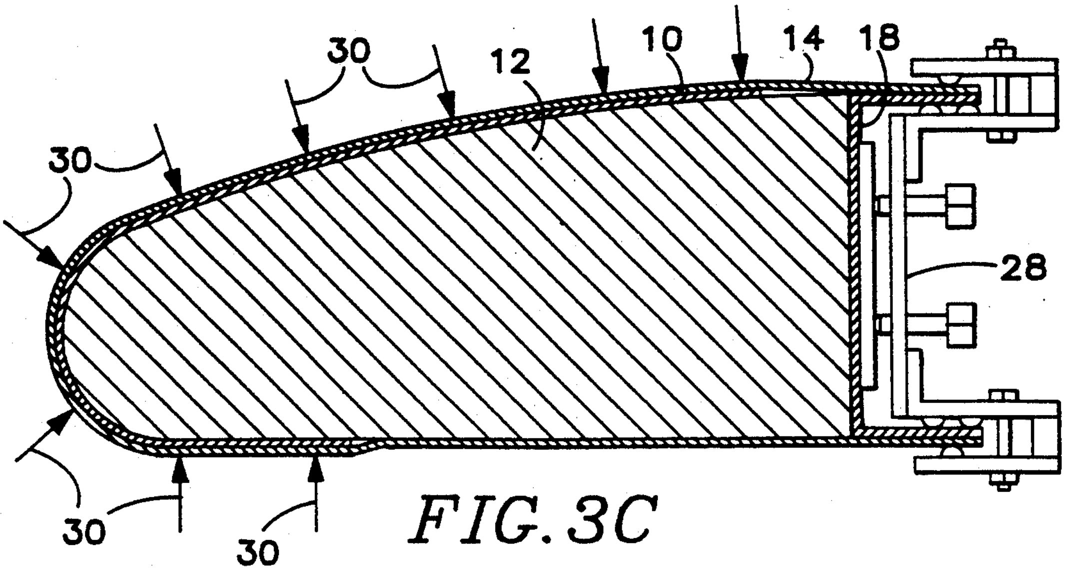


FIG. 3C

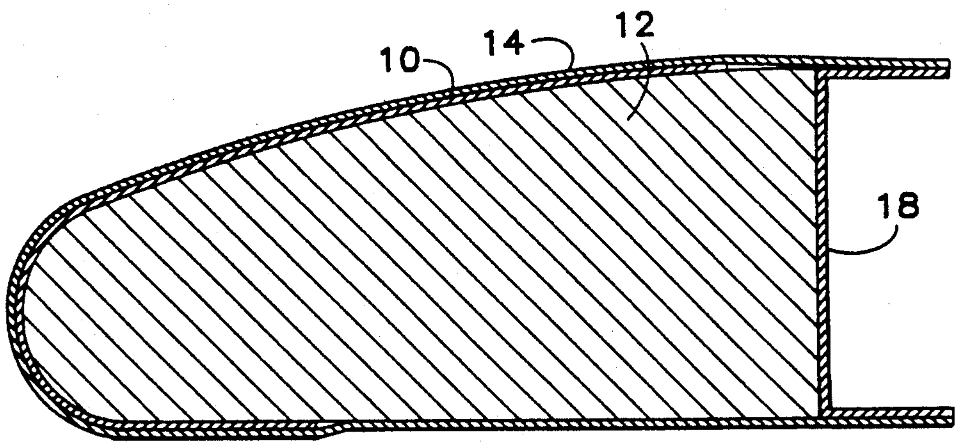


FIG. 3D

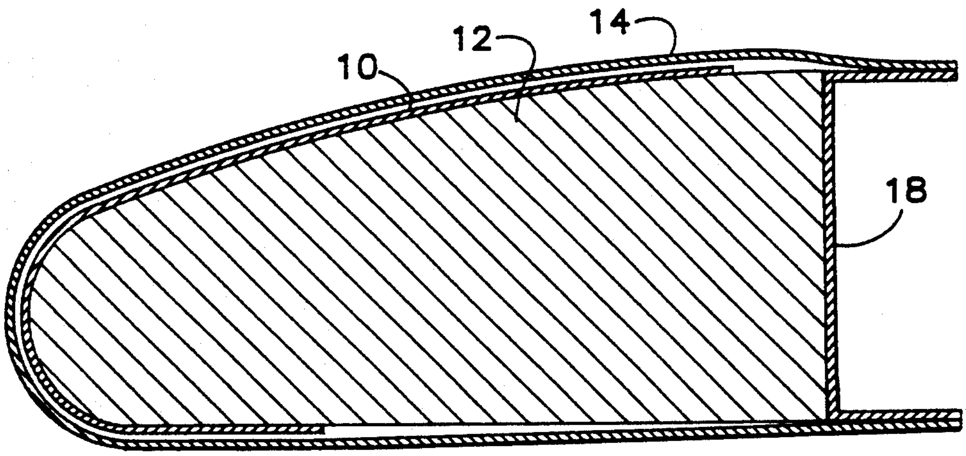


FIG. 3E

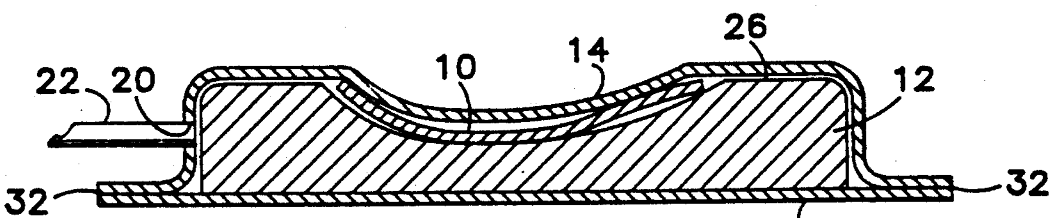


FIG. 4A

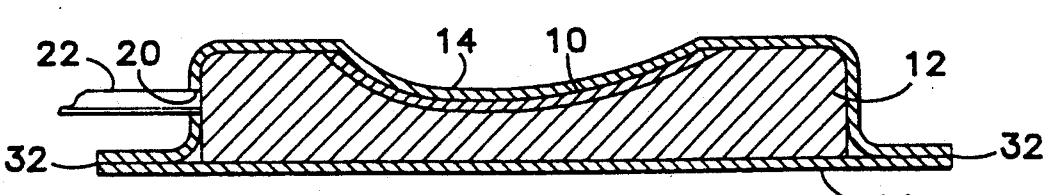


FIG. 4B

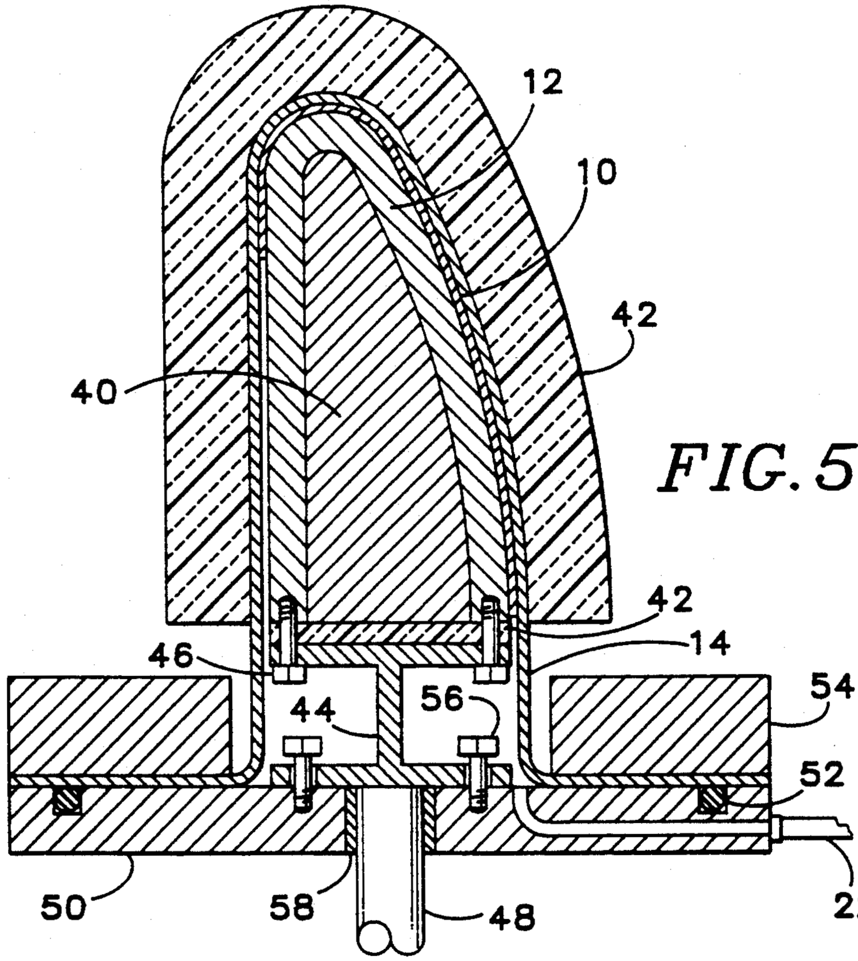


FIG. 5

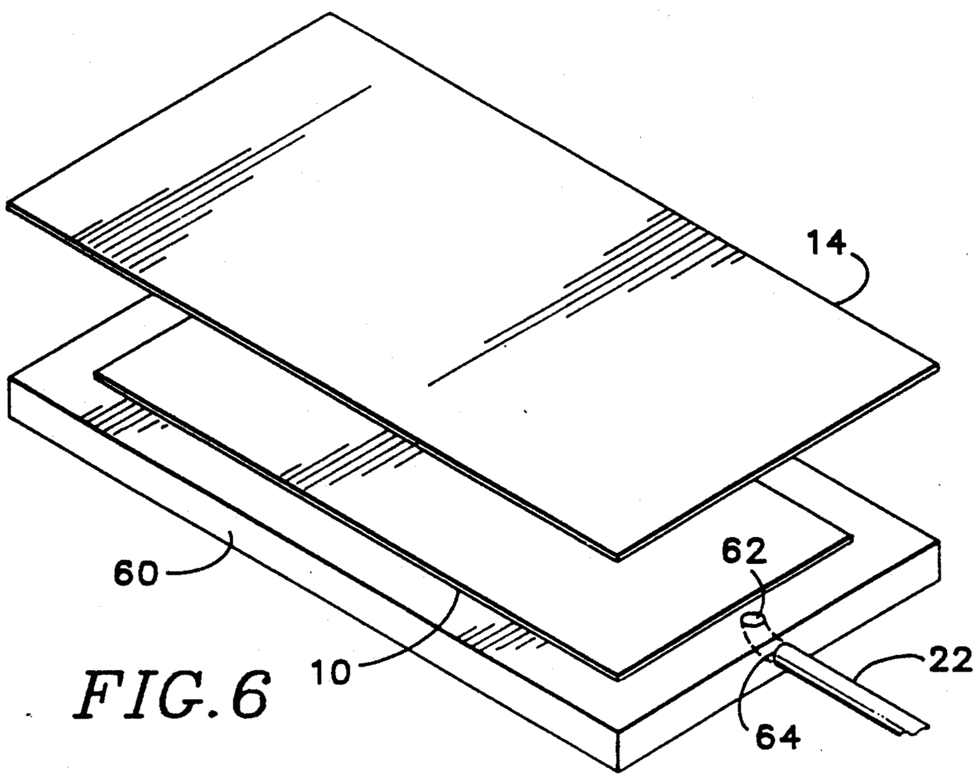


FIG. 6

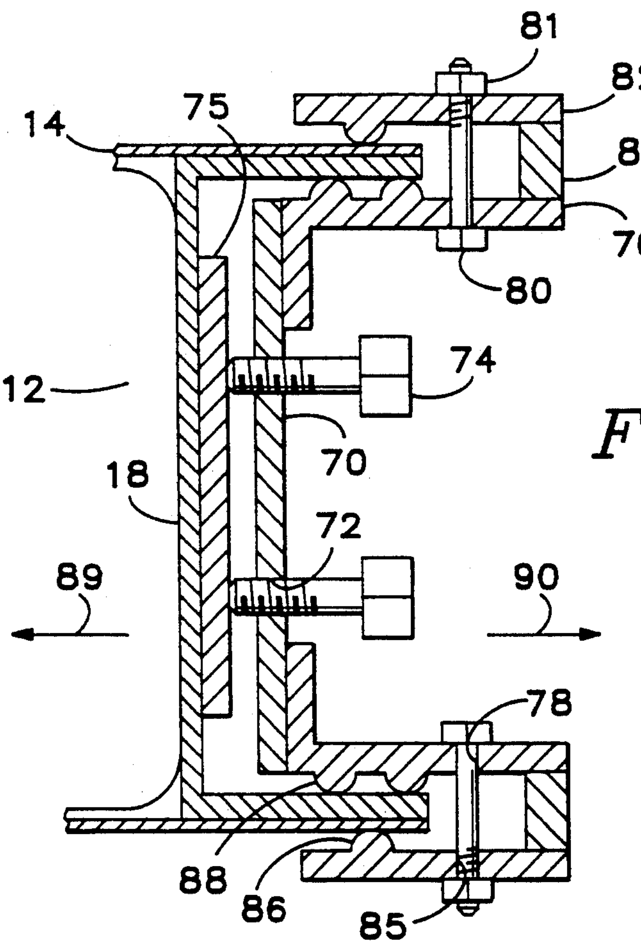


FIG. 7

28

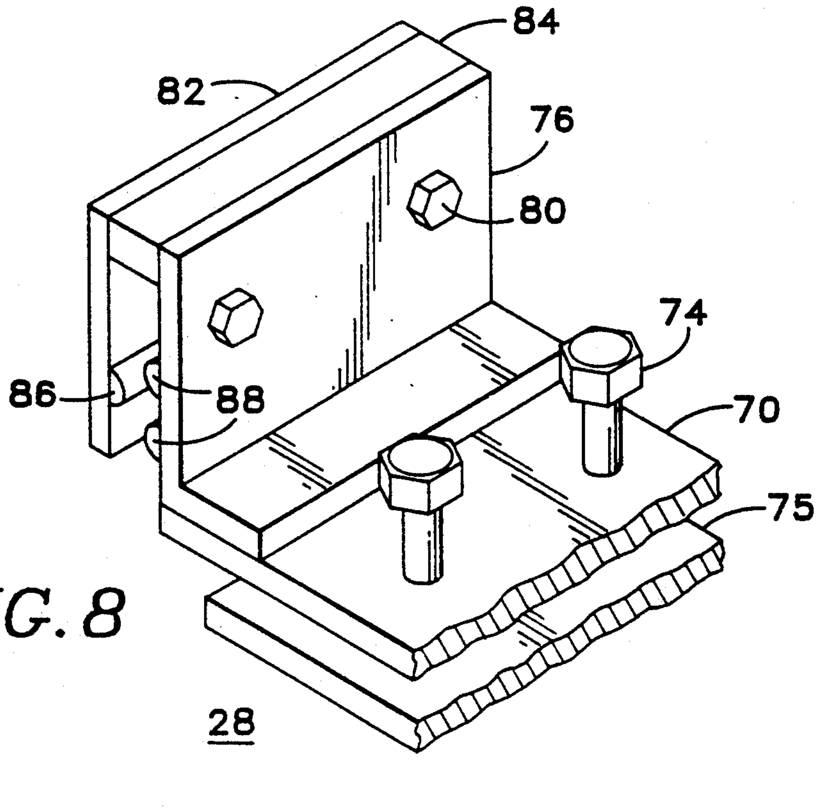


FIG. 8

28

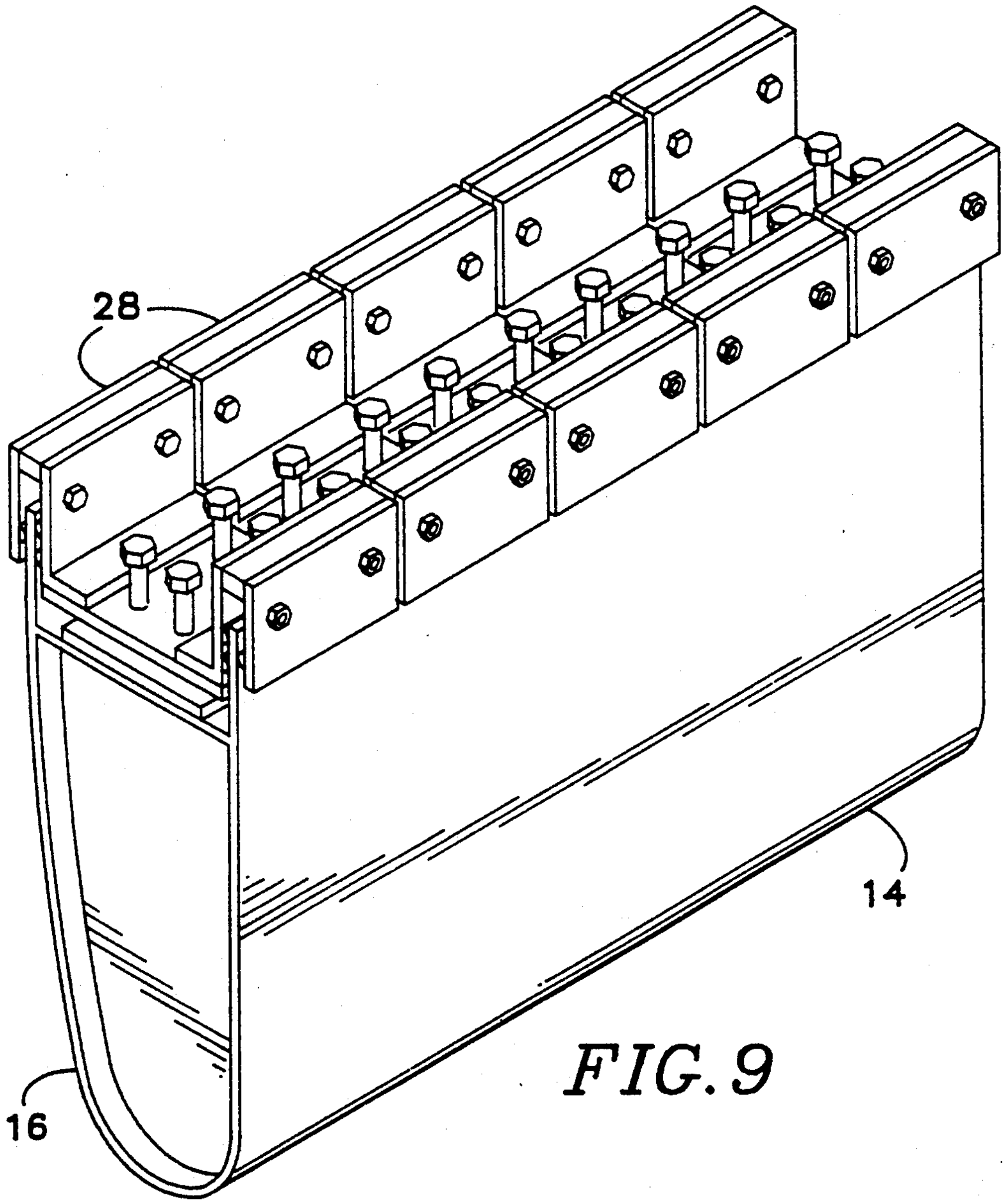


FIG. 9

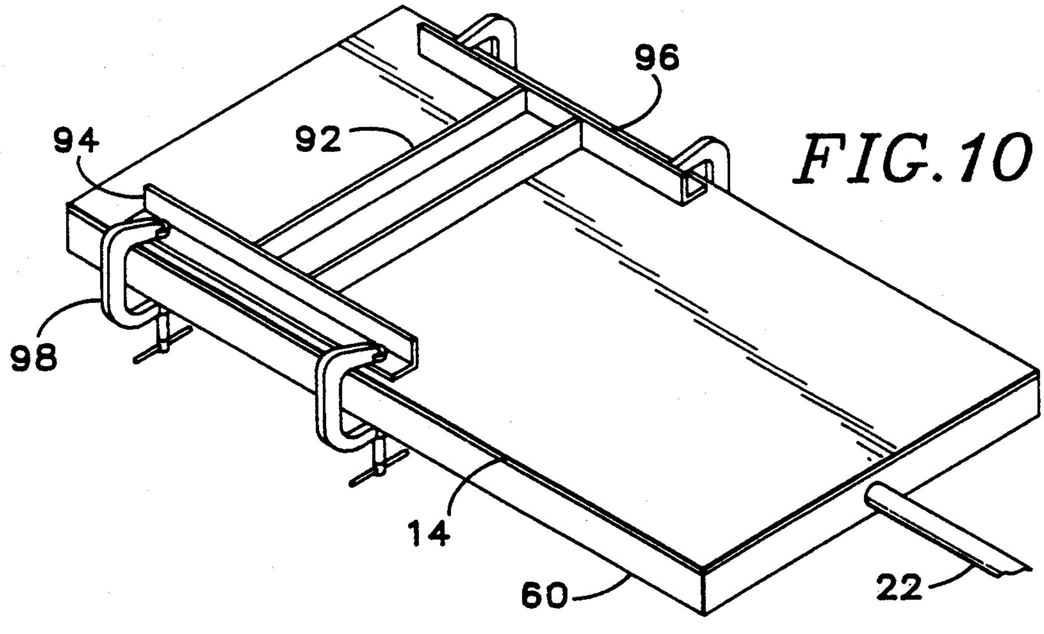


FIG. 10

ELEVATED TEMPERATURE ENVELOPE FORMING

BACKGROUND OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract NASI-18574 and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1948, Public Law 85-568 (72 STAT.435: 42 USC 2457).

The present invention relates to elevated temperature envelope forming and more particularly to a method of forming a skin for airfoils. An aircraft wing surface in flight is characterized by friction between the air and the wing, usually resulting in turbulence and undesired drag. In order to reduce drag and excessive airplane fuel consumption it is desirable to replace turbulence with laminar flow to the extent possible wherein the airflow over a wing surface is relatively smooth. One kind of flow control termed natural laminar flow (NLF) is accomplished through manufacture of precise wing surfaces having a minimum of waviness and roughness. In another method for improved air flow, termed laminar flow control (LFC), the air layer near the surface of the airfoil is drawn through small holes in the airfoil surface with some form of pumping and ducting being used to remove the otherwise turbulent layer through the holes after which the air is vented to the atmosphere away from the airfoil. Still another method combines NLF and LFC to provide hybrid laminar flow control (HLFC) wherein perforations are provided on the leading edge skin of a wing to withdraw an air layer, together with the use of a precision wing surface.

Leading edge wing skins, e.g. as formed of titanium sheet, are typically shaped in a stretch process. However, the provision of perforations in a leading edge skin for laminar flow control is not particularly compatible with stretch forming since stretching tends to elongate preformed holes and distort flow control. The process of creating the perforations in the skin can itself introduce waviness and distortion. Hot forming employing matched dies is not acceptable in the case of preperforated skins because desired waviness tolerance is not easily attained or corrected. Also, contamination from protective coatings normally used in a matched die hot forming process can plug the holes or increase the hole size, e.g. when the coating is removed.

SUMMARY OF THE INVENTION

In accordance with the present invention in a particular embodiment thereof, a process of elevated temperature envelope forming includes placing a perforated sheet metal part blank, which may be preformed to approximately the desired shape, against a form tool, enclosing the part blank and form tool within an envelope, and sealing the envelope against the atmosphere to create a retort. External force is applied to urge the form tool and blank together for constraining the part toward the desired configuration. The retort is evacuated whereby outside air pressure is applied against the envelope, and when the vacuum reaches a sufficient level, the external force is removed and heat treatment is begun. Once the heat treatment is complete, the vacuum within the retort is released and replaced with an inert atmosphere as the retort is allowed to cool.

It is accordingly an object of the present invention to provide an improved method and apparatus for forming a sheet metal part within desired tolerance while preventing contamination of the part's surface.

It is another object of the present invention to provide an improved method and apparatus for forming wing leading edge skins from perforated titanium sheets having a finished waviness tolerance of +/−0.001 inches in two inches.

Another object of the present invention is to provide an improved method and apparatus for thermal processing which reduces the effects of different thermal expansion rates between a part and a forming tool.

It is also an object of the present invention to provide an improved method and apparatus for flattening metal sheets to meet high tolerance requirements.

The subject matter of the present invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. However, both the organization and method of operation, together with further advantages and objects thereof, may best be understood by reference to the following description taken in connection with accompanying drawings wherein like reference characters refer to like elements.

DRAWINGS

FIG. **1** is an exploded perspective view of a forming retort for a leading edge of an airplane wing;

FIG. **2** is a perspective view of the assembled retort of FIG. **1**;

FIGS. **3A–3E** are cross sectional views of the forming retort of FIG. **2** for various phases of preparation for heat treatment and thereafter;

FIGS. **4A** and **B** are cross sectional views of a retort with a female form tool, before and after vacuum is applied;

FIG. **5** is a cross sectional view of an alternate method of envelope forming using an integrally heated forming tool;

FIG. **6** is a perspective view of the present invention applied to sheet metal flattening;

FIG. **7** is a cross sectional view of an assembled retort showing the clamp of FIG. **3** in greater detail;

FIG. **8** is a cut-away perspective view of a portion of the clamp of FIG. **7**;

FIG. **9** is a perspective view of an assembled retort with a plurality of clamps attached thereto; and

FIG. **10** is a perspective view of a clamping device for holding the envelope tight against a flattening plate during sealing.

DETAILED DESCRIPTION

Referring to FIG. **1** comprising an exploded view of a retort used for forming a desired part, the part **10**, which may comprise a perforated sheet of titanium suitable for the leading edge of an airplane wing, is placed against form tool **12** contoured within desired tolerance to the shape which is ultimately desired for the part **10**. Form tool **12** is suitably constructed of steel. Once the part is placed over the form tool, an envelope outer skin **14** is wrapped around form **12** and part **10**, and end pieces **15** and **16** as well as back channel piece **18** are welded to the envelope skin to provide an atmospheric seal around part **10** and the form tool completing a retort. In the preferred embodiment, envelope skin **14**, end pieces **15** and **16** and back piece **18** comprised stainless steel members having a thickness of approximately 0.032 inch, while part **10** comprised titanium sheet having a thickness of 0.040 inch. Stainless steel was chosen as envelope material partly because it does not react with titanium and is relatively clean, i.e., normally free of surface contaminants such as oil, which could contaminate the part.

Envelope end **16** is provided with an opening or fitting **20** connected to vacuum/argon supply line **22** for evacuating the atmosphere within the enclosed envelope and for providing an argon atmosphere at appropriate times within the envelope as subsequently discussed herein in connection with FIGS. **3C–3E**. Placement of the vacuum supply opening is not critical; it is simply necessary to choose a location that will not result in the vacuum hole becoming plugged during evacuation and heating. Tool support beams **24** are placed below the entire assembly and raise the retort to allow heat circulation underneath. FIG. **2** is a perspective view of the retort after the envelope has been sealed.

After envelope sealing, force is applied to the rear **18** of the retort to push form tool **12** against the envelope, thereby pressing the part **10** against the forming tool. Once this external forming pressure is applied, a vacuum is drawn within the retort via vacuum line **22** and the physical pressure at the rear **18** of the retort is removed since friction between the envelope, part and tool coupled with the vacuum holds the part tightly against the tool. External forming pressure may not always be necessary since the vacuum alone may suffice. However, some tool shapes may be such that when vacuum is first applied a large part surface area may contact the envelope first, trapping air and leaving insufficient envelope pressure against the part. The retort should be constructed to be nearly form fitting to the shape of the form tool since if the retort is not reasonably form fitting, the welded seams can crack after vacuum is applied and allow vacuum leakage. The envelope skin **14** is quite collapsible to adhere closely to the part and the tool.

The entire assembly is then placed within a furnace (while maintaining the vacuum) for heat treatment to relieve residual stresses and insure the part takes on the desired shape. Performing the stress relief under a vacuum is desirable to minimize contamination of the part.

FIG. **3** comprises cross sectional views of the envelope and part forming tool during various stages of the forming operation. FIG. **3A** illustrates the envelope before forming pressure has been applied, but after the envelope has been sealed, and it is seen hollow areas **26** may exist at locations where the part **10** is not snug against form tool **12**. Referring now to FIG. **3B**, forming pressure has been applied wherein clamp assembly **28** is attached to the rear of the envelope **18** and used to force the form tool forwardly within the retort pulling envelope skin **14** more closely against the form tool. The operation of clamp assembly **28** will be discussed subsequently in connection with FIGS. **7–9**. Once the clamp force has pulled the envelope skin fairly taut, vacuum pressure is provided via vacuum line **22**, not illustrated in FIG. **3**, and the external atmospheric pressure adheres the envelope snugly against form tool **12** and the intervening part **10**. The effect of external atmospheric pressure against the part and form tool is illustrated by arrows **30** in FIG. **3C**. Once the vacuum has been provided, clamp assembly **28** can be removed (FIG. **3D**) and the envelope part and tool are ready for heat treatment.

FIG. **7** is a cross sectional view showing clamp **28** of FIG. **3** in greater detail, while FIG. **8** is a cut-away perspective view of a portion of the clamp. Clamp assembly **28** fits behind the retort back channel member **18** of FIGS. **1** and **3**, opposite form tool **12**, and includes clamp base plate **70** having threaded holes **72** for receiving pusher bolts **74**. In the preferred embodiment, the clamp base is provided with four threaded holes **72** evenly spaced in the plane of the base plate so as to distribute pressure from the bolts. The bolts **74** threadably engage the holes, and when tightened, push against pressure plate **75** engaging channel member **18**. Clamp base flanges **76**, having their front faces attached to the base plate **70** near its perimeter at opposing edges thereof, are provided with openings **78** near the rear of each flange for receiving bolts **80**. Clamp top members **82**, joined to flanges **76** by outwardly extending spacers **84** to complete a U-shaped cross-section, are arranged to be approximately coextensive with the clamp base flanges and have holes **85** through which bolts **80** extend for receiving nuts **81**. Each clamp top member **82** is provided with a gripper seam **86** while clamp base flanges **76** each carry a pair of spaced gripper seams **88** disposed on either side of seam **86**. In operation, bolt **80** is passed through flange holes **78** and **85** and nut **81** is threaded onto the bolt. The rear "ears" of the assembled retort (comprising envelope **14** welded to envelope **18**) are fed between flange gripper seams **86** and **88** and nuts **81** are tightened. Pusher bolts **74** are then tightened, exerting force on pressure plate **75**, causing the pressure plate to push form tool **12** forwardly in the direction of arrow **89**, while the clamp assembly (via grippers **86** and **88**) is pulling the envelope backwards in the direction of arrow **90**. It will be noted channel member **18** can be distorted somewhat. FIG. **9** is a perspective view of an assembled retort having a plurality of clamps **28** attached thereto.

After the vacuum is applied and the clamps are removed, the retort is placed in a furnace for heat treatment. When the heat treatment is completed and the cool down cycle has begun, the pressure holding the part against the form tool should be released to prevent wrinkling of the part as may be caused by the differing rates of thermal expansion of the part and the form tool. According to the present invention it is preferred to release the vacuum and pressurize the envelope with an inert gas, for example, argon, after the heating is finished. This pressure fills the envelope as shown in FIG. **3E** and allows the part to freely contract, preventing the part from wrinkling.

The invention allows relatively inexpensive materials to be used as form tools, for example, carbon steel, when forming part metals such as titanium which may not have like thermal expansion rates, ASTM A-36 steel plate being used as form tool material in a particular embodiment. An inert gas is used because it inhibits contamination of the part; in a preferred embodiment, the retort was pressurized to approximately 10 inches H_2O positive pressure with argon gas. Part contamination may be further reduced in the initial portion of the process by purging the retort with the inert gas for a period of time (e.g. 8 hours) before applying the vacuum and heat stress relief. Both thermal expansion and part contamination problems are lessened by using the lowest possible temperature for stress relief. For instance, stress relief treatment may suitably comprise heating the retort to 1,000 degrees Fahrenheit for one hour.

While the foregoing example has illustrated a male form tool, the present invention is also applicable to part forming with a female tool as shown in FIG. **4**. In FIG. **4A**, part **10** is placed against form tool **12** and surrounded by envelope **14**, sealed as by welding at various points indicated by reference numerals **32**. Vacuum supply line **22** is provided via orifice **20** to maintain a vacuum within the envelope whereby hollow spaces **26** are removed by external atmospheric pressure against the envelope **14** resulting in the configuration illustrated in FIG. **4B**.

FIG. **5** illustrates a cross sectional view of an alternative method of forming parts at elevated temperature. Part **10** is placed around form tool **12**, the latter including a heater element **40**, empowered by means not shown, contained within the hollow center thereof whereby the necessary heat can be supplied for the stress relief for insuring the part will take on the desired shape. Envelope **14** surrounds the part and tool while insulation **42** is suitably disposed in surrounding relation to the envelope. Insulation may also be included at the base of the form tool where the latter is attached to riser platform **44** by means of bolts **46**. Platform **44** is mounted upon an envelope tightener **48** suitably comprising a hydraulically operated rod extending upwardly from a hydraulic cylinder (not shown). Envelope **14** is sealed against the atmosphere by means of underlying base plate **50** upon which platform **44** initially rests, an 0-ring seal **52**, and a heavy "picture frame" **54** for pressing the periphery of envelope **14** tightly against base plate **50**. Envelope **14** extends continuously from one edge of base plate **50**, around the part and form tool, to the opposite edge of the base plate, and is further sealed at either end by means not shown. Vacuum supply **22** is connected through a passage in the base plate for evacuating the envelope during heat forming, and for supplying an inert atmosphere during the cool down period once the vacuum is released.

The maximum range of upward motion of hydraulic tightener **48** is determined by means of shoulder bolts **56** threadably attached to base plate **50** and passing through openings in platform **44** whereby platform **44** may translate only along the length of bolts **56**. A seal **58** is provided at the location where rod **48** passes through base plate **50**, to insure maintenance of a vacuum in the part forming chamber during the foregoing procedure.

The high density perforation patterns initially created in sheet metal skins used for airplane wing portions in laminar flow control applications can lead to significant distortion of the metal sheet. Furthermore, when the part is first preformed to roughly approximate the desired final shape before final forming, distortion can make the preforming process difficult. It is desirable to at least insure the sheet metal skin is initially planar. Referring to FIG. **6**, a flattening plate **60** is provided having a vacuum hole **62** on the upper face thereof, such vacuum hole **62** being connected via an inner passage in plate **60** to vacuum line **22** through fitting **64**. The sheet metal part **10**, of smaller planar dimension than plate **60**, is placed on top of the flattening plate and top sheet **14** typically of the same planar dimension as flattening plate **60** is placed over the part forming a sandwich. The sandwich is sealed to the atmosphere, for example by welding the top sheet to the flattening plate along the perimeter thereof. To ensure the envelope and part **10** fit as snugly as possible against the flattening plate, the envelope and sheet are suitably held against the flattening plate during welding, for example by placing weights on top of the envelope.

In the preferred embodiment, a clamping device was constructed to hold the top sheet and part against the plate during welding. Referring now to FIG. **10**, such clamping device comprises a channel member **92** extending substantially across the width of envelope sheet **14** and attached by welding at opposite ends thereof to right angle flanges **94** and **96** adapted to extend along a portion of the perimeter of the envelope in perpendicular relation to channel member **92**. Ordinary C-clamps **98** are employed to hold the clamping device firmly against the flattening plate. Once the envelope edges are sealed, the C-clamps and clamping device can be removed. The "sandwich" is placed within a furnace after the atmosphere within the sandwich is evacuated via vacuum tube **22** to pull the top sheet taut for pressing the part against the flattening plate and removing waviness or distortion in the part. The heat treatment insures the part will take on the flat shape of plate **60**. When a cooling period subsequently takes place, the vacuum within the envelope is released and the envelope may be provided with an atmosphere of an inert gas, relieving the pressure, and allowing the part to move and accommodate for varying thermal expansion rates. Once cool down has finished, the top sheet is peeled away. In a specific embodiment, top sheet **14** comprised 0.032 inch thick stainless steel, part **10** comprised 0.040 inch thick titanium and flattening plate **60** comprised a flat steel plate one inch in thickness.

While several embodiments of the present invention have been shown and described, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from the invention in its broader aspects. The appended claims are therefore intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

We claim:

1. A method for forming a sheet metal part comprising the steps of:
- placing a part blank against a form tool;
- enclosing said part blank and said form tool within a flexible envelope by at least partially wrapping said envelope around said part blank;
- sealing said envelope against atmospheric pressure;
- providing a vacuum within said envelope for holding said envelope against said part blank in substantially form fitting engagement with said forming tool; and
- heating said envelope, said part blank and said form tool for a period of time thereby forming the sheet metal part.

2. The method according to claim **1** further including providing differential force between said form tool and said envelope to urge said part against said form tool.

3. The method according to claim **1** further comprising perforating said part blank with a plurality of apertures.

4. The method according to claim **1** further comprising the step of purging the enclosed portion of said envelope with an inert atmosphere for a period of time after said step of sealing said envelope and before providing a vacuum.

5. A method for forming a sheet metal part comprising the steps of:
- placing a part blank against a form tool;
- enclosing said part blank and said form tool within an envelope;
- sealing said envelope against atmospheric pressure;

providing a vacuum within said envelope for holding said envelope against said part blank;

heating said envelope, said part blank and said form tool for a period of time; and

replacing said vacuum with an inert atmosphere once the heating period is complete thereby forming the sheet metal part.

6. The method according to claim **5** wherein said step of replacing said vacuum with an inert atmosphere comprises providing Argon.

7. A method for forming a sheet metal part comprising the steps of:

placing a part blank against a form tool;

enclosing said part blank and said form tool within a stainless steel envelope;

sealing said envelope against atmospheric pressure;

providing a vacuum within said envelope for holding said envelope against said part blank; and

heating said envelope, said part blank and said form tool for a period of time thereby forming the sheet metal part.

8. A method for forming a sheet metal part comprising the steps of:

preforming a part blank to be approximately the shape of a form tool;

placing said part blank against said form tool;

enclosing said part blank and said form tool within an envelope;

sealing said envelope against atmospheric pressure;

providing a vacuum within said envelope for holding said envelope against said part blank; and

heating said envelope, said part blank and said form tool for a period of time thereby forming the sheet metal part.

9. A method for forming a portion of an airfoil to within strict waviness tolerances comprising the steps of:

perforating said portion with a multiplicity of apertures;

placing said airfoil portion around a convexly shaped form tool adapted to provide the final configuration of said portion;

enclosing said airfoil portion and said form tool within an envelope, at least a portion of said envelope having relatively high collapsibility properties;

sealing said envelope against atmospheric pressure;

providing external force inwardly against said convexly shaped form tool relative to edges of said envelope;

providing a vacuum within said envelope for pulling said envelope tightly against said form tool;

removing said external force while maintaining said vacuum; and

heating the combination of said envelope, said airfoil portion and said form tool for a period of time.

10. The method according to claim **9** further comprising the step of releasing said vacuum and providing an inert replacement atmosphere after the heating period.

11. Apparatus for forming a sheet metal part comprising:

a forming tool of the shape to which the part is to be formed;

a flexible envelope member for holding said part in substantially form fitting engagement with said forming tool;

means for atmospherically sealing the part against said forming tool to provide an enclosure and for drawing a vacuum therewithin; and

means for physically urging the part against said forming tool.

12. Apparatus according to claim **11** wherein said means for physically urging the part comprises hydraulic means.

13. Apparatus for flattening a metal sheet comprising:

a flat plate;

a flexible envelope for enclosing said sheet and at least a portion of said plate for forming a chamber, said sheet being disposed within the chamber between said plate and said envelope;

means for atmospherically sealing said chamber; and

means for withdrawing air from said chamber.

14. A method for flattening a metal sheet comprising the steps of:

placing the metal sheet against a flattening plate;

sealing the metal sheet and at least part of the flattening plate within a flexible envelope;

evacuating the envelope; and

heating the metal sheet for stress relief while maintaining the evacuated state of said envelope.

15. A method for flattening a metal sheet comprising the steps of:

placing the metal sheet against a flattening plate;

sealing the metal sheet and at least part of the flattening plate within an envelope;

evacuating the envelope;

heating the metal sheet for stress relief; and

providing the envelope with an inert atmosphere after heating is completed.

* * * * *